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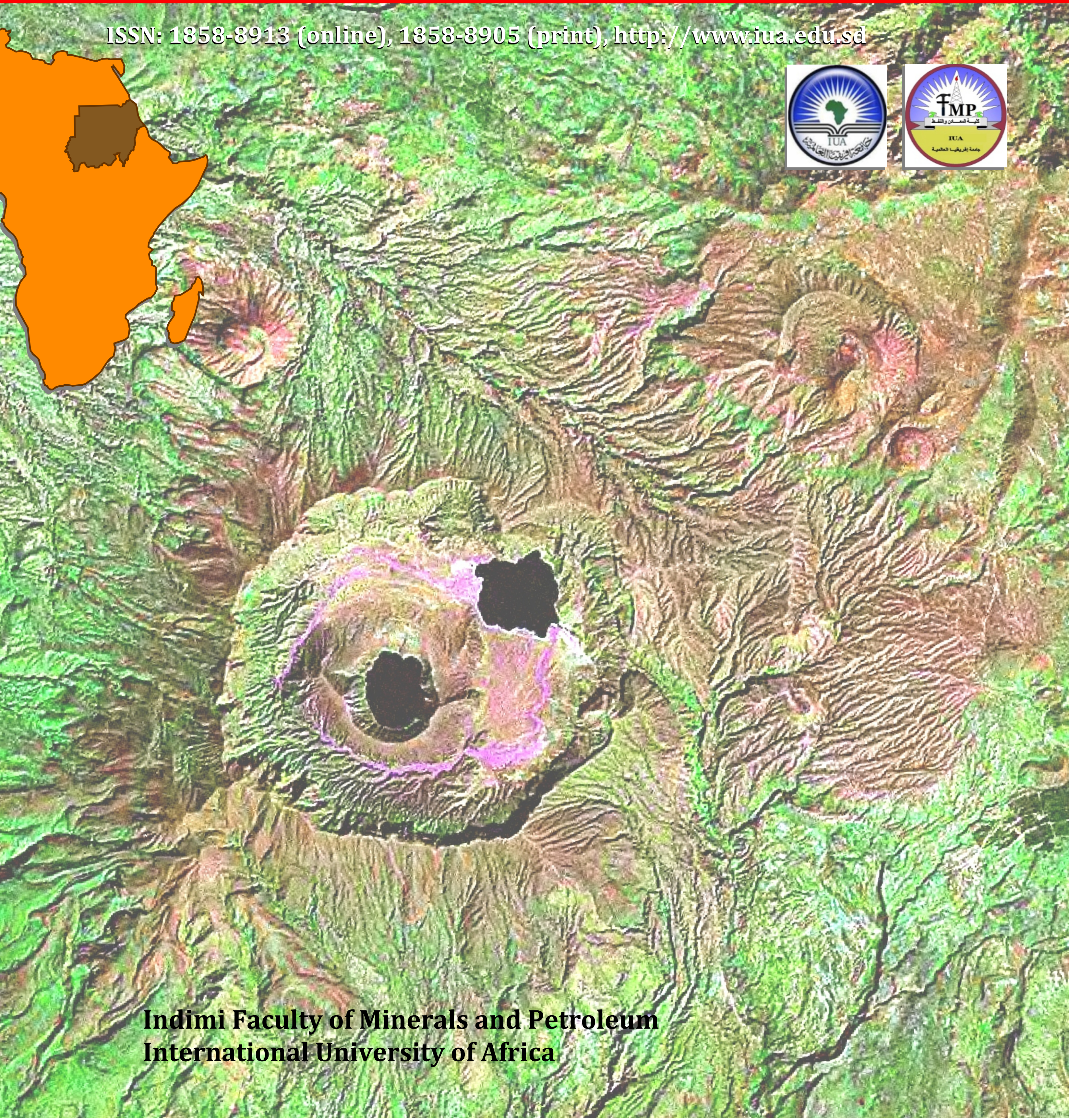

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Geo-electrical Investigations for Groundwater Exploration in the Area Between Wad El Helew and Khashm El Girba Towns, River Atbara Valley, Eastern Sudan

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Abstract

Geophysical investigation has been carried out to explore the groundwater occurrence in the area between Wad Elhelew and Khashm El Girba towns, Kassala and Gedaref States, eastern Sudan. Vertical electrical sounding technique was applied using Schlumberger Array (configuration), with a maximum half separation AB/2 = 900 -1000 m. The study area covered by (177) points of vertical electrical sounding (VES) measurements distributed to cover the study area at the both sides of the River Atbara and Setit, (Figure 9). The VES points distributed to fill the gabs where there are no wells and to detect the boundary of the aquifers. Based on variations in apparent resistivity of various formations and sequences the study area was divided into three sectors; upstream area, Middle area and downstream area. Three geo-electrical sections constructed in the study area in E-W direction. From the data interpretation; the Aquifer zones in the study area seems to be wider upstream and gets narrower downstream. The water bearing formations in the study area consist of; River Atbara sediments extended from the midstream area to downstream area, Cretaceous sandstone which occurs in the upstream part of the study area including (Wad Elhelew area, Upper Atbara / Setit dam's area, Showak area and Um Gargoor area). The Saturated fractured basaltic rocks covered the area attached to the River Atbara banks and recharged directly from the river in the downstream area. Generally in the study area the resistivity values of the superficial deposits range from 2 to 300 Ω.m, the resistivity values of the River Atbara sediments range from 20 to 120 Ω.m, the resistivity values of the basalts range from 100 to 300 Ω.m, the resistivity values of the Cretaceous sandstone range from 20 to 80 Ω.m and the resistivity values of the basement complex ranges from 200 to 600 Ω.m. River Atbara sediments and Cretaceous sandstone layers are considered the main water bearing formation in the study area.

Keywords: Geophysical exploration, electrical resistivity, groundwater occurrences, eastern Sudan.

1. Introduction

There are many geophysical methods known worldwide applied in geological exploration such as gravity, magnetic, electromagnetic, seismic and resistivity methods. Geophysical methods can help in solving the problem through the detection of occurrence, depth and thickness of the subsurface layers (El-Galladi et al., 2007). The resistivity method is most common method used in groundwater exploration. The electrical resistivity of a medium depends mainly on groundwater salinity, saturation, aquifer lithology, and porosity (Shaaban, 2002). This property has been success fully used to explore for groundwater and its condition (Al-Garni, 2009). The vertical electrical sounding technique is used to determine variations in electrical resistivity with thickness (depth) and resistivity values of the layers, whereas, profiling is used for delineating geological structures or reflect lateral changes in electrical resistivity corresponding to variations in lithology, weathering, fracturing, thickness of layers and water content (Okereke et al.,1998). The most commonly arrays used for resistivity surveys are Wenner Spread, Schlumberger Spread, Three-Point Spread, Dipole-

Dipole Spread and Lee-Partition Spread (Telford et al., 1982). The choice of the "best" array for a field survey depends on the type of structure to be mapped, the sensitivity of the resistivity meter and the background noise level (Hago, 2000). The aims of geophysics are to reduce the high cost of drilling and to achieve the above mentioned objectives (Milsom, 2003). However, the VES data generally reflect the relation between the groundwater occurrence and the resistivity of the water-bearing formation. The main task of the electrical sounding method in this study is to identify resistivity zones which are related to the groundwater occurrences of good quality and quantity.

Several geological, hydrological, hydrogeological and geophysical investigations were carried out in the study area. Hussein et al. (1989) made Geological and Seismic investigations to shallow groundwater explorations in River Setit deposits and in the Nubian, near Abuda village. Ibrahim et al. (1992) Applied combine geophysical and hydrogeological investigations for groundwater exploration at Showak – Wad Elhelew area, Eastern Sudan, and evaluated the groundwater potential and two major basins were identified: Wad Elhelew with maximum thickness of 2.2 km and Showak basins is shallower with maximum thickness not exceeding 0.25 km. Hussein et al. (1995) performed a water quality investigations in the Gedaref basin. They analyzed the groundwater in sandstone aquifer and fractured basaltic rocks aquifer. Fadull et al. (1999) carried out studies to estimate the gross of the Karab lands along the River Atbara and its tributaries. They estimated the rate of annual loss of arable land caused by gully erosion, and its environmental effects. Eisawi and Schrank (2009) have studied the terrestrial palynology band age assessment of the Gedaref formation. Elsheikh et al. (2014) identified the geological units and estimated the groundwater budget of the River Atbara sediments, between El Girba and New Halfa.

Generally the above studies have confirmed that the Gedaref basin structure formed of sedimentary sequences intruded by volcanic rocks with groundwater potentialities and chemically plotted within alkaline to sub alkaline series and sometime with a problem of water quality. Regarding these studies and in the areas near River Atbara and Setit, two major basins were identified, namely; Wad Elhelew and Showak basins.

2. Study area

The study area lies in the eastern Sudan in Kassala and Gedaref states, the eastern part of the study area situated in Kassala state while the western part of the study area located in Gedaref state. The study area bounded by latitudes 14.134170º N to 14.961004º N and longitudes 35.536336º E to 35.962208º E. The study area is of irregular shape covering an area of about 3000 Square kilometres, (Fig. 1). The study area is located in arid and semi-arid zones. The climate is characterized by long hot summer with short cold winter. Where summer is almost from April to October, it is hot and dusty. Winter from November to March it is very pleasant and cool. The winds usually come from the north, (Saeed, 1969).

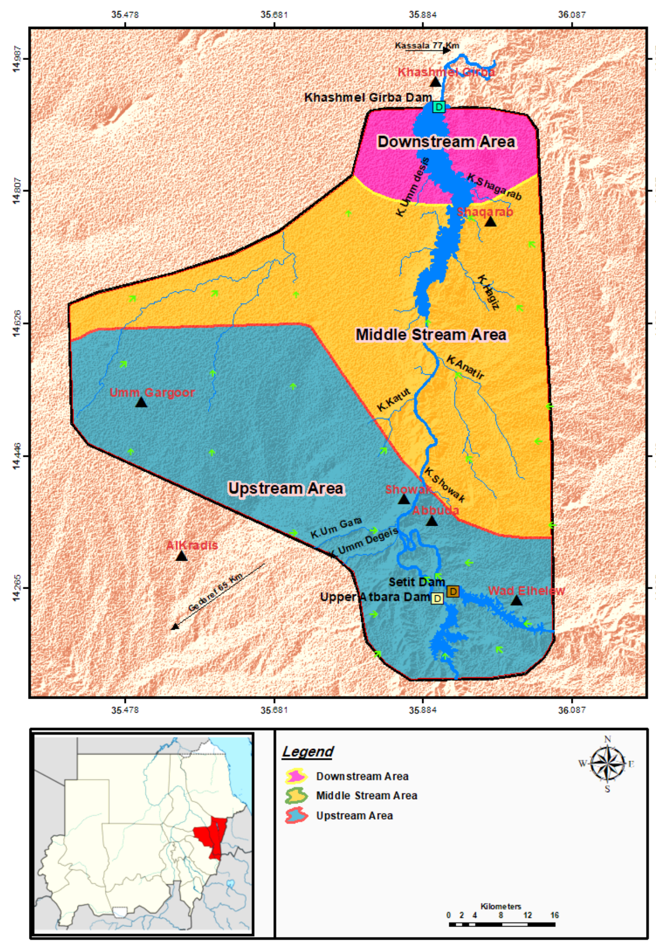


Fig. 1. Location and sectors of the study area.

A range of 425 – 1165.8 mm\year rainfall characterizes the study area. The rainy season consist of only a few days in four months with heavy rains, the rainy season starts in July and lasts until October. The River Atbara flows through four different climatic zones: dry sub- humid, semi – arid, arid and hyper - arid zones, (Fadull et al., 1999). The natural vegetation is mainly Talih trees (Acacia seyal) and Kitir trees (Acacia mellifera), with tall grasses in the semi-arid zone. Samor trees (Acacia tortillis) dominate in the arid zone.

3. Geological and structural setting

Some authors studded the area of River Atbara and Setit and described the geological units of the area such as (Hussein et al., 1989; Ibrahim et al., 1992; Hussein and Adam, 1995; Fadull et al., 1999). They were summarized the geological units from bottom to top as follows: Precambrian – Cambrian basement complex), Nubian sandstone (Cretaceous), Basaltic intrusions (Tertiary), River sediments (Quaternary), Karab Formation (Quaternary/Neogene) and Cracking black Clays (Black cotton soil) (Quaternary/Neogene). In the study area the main hydrogeological units constitute the aquifer system are; weathered and fractured Pre-Cambrian basement rocks, Cretaceous Sedimentary rocks, Cainozoic Basalts, Rivers Atbara and Setit sediments, Unconsolidated Karab formation and the superficial deposits, (Fig. 2).

The geological structures represented by; folds, faults, fractures and joints. According to the regional and detailed geological survey that had been conducted in the study area, three major faults in N-S and E-W direction had been detected. Two of them are normal faults represent the boundaries between the basement rocks, basaltic rocks and Craterous sedimentary rocks. Other major fault located on the eastern bank of the River Setit in SE-NW direction, (Fig. 2).

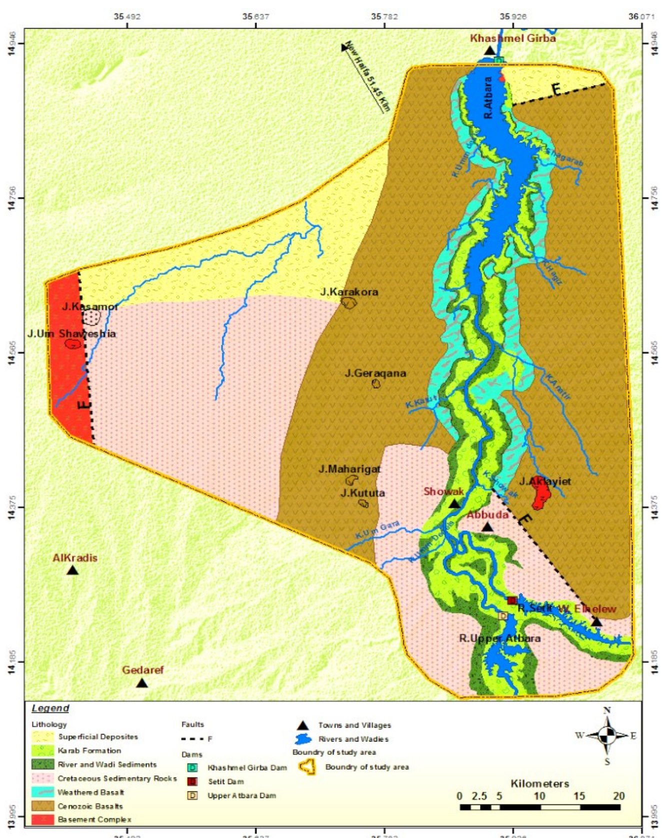


Fig. 2. Geological map of the study area

4. Methodology

In the current investigation the Electrical Resistivity method has been used. Vertical electrical sounding (VES) techniques is considered as the most significant techniques for groundwater exploration for detecting the vertical variations of subsurface sequences which was conducted to verify the goals of this research. Schlumberger Array (configuration) was used during the whole survey, with a maximum half separation AB/2 = 900 -1000 m.

The study area covered by (177) points of vertical electrical sounding (VES) measurements distributed to cover the study area at the both sides of the River Atbara and Setit, (Figure 9). The VES points distributed to fill the gabs where there are no wells and to detect the boundary of the aquifers. The VES measurements have been conducted using an ABEM SAS-1000 Terrameter (Sweden). The VES curves are interpreted with IPI-2WIN software.

5. Data interpretation

The acquired measured resistivity data was analysed qualitatively based on shapes of the plotted curves and quantitatively by measuring the layers resistivity values and depths through capable software.

5.1 Qualitative interpretation

The geological knowledge of the study area is the most important in qualitative interpretation in which the general shape of the curves and the primary apparent resistivity of various formations were recognized. Most of the field curves type is in HA, AH, HKH and KH, reflecting 6 to 7 layers. The relatively low resistivity occurred in the upstream part of the study area. Sometimes (A) curve type especially in the downstream area, indicating 3 to 4 layers which reflecting the existence of basaltic rocks with high resistivity values. The relative resistivity values in the field curve for the aquifer is range between (20 – 100) Ωm. The smooth shape of the curve indicates relative homogeneity of the geological formation. The very low resistivity values which is ranging between (0 - 5) Ωm that occurred in the middle area indicating saline water or clayey layer.

5.2 Quantitative interpretation

Interpretation of geophysical data can be completely objectives. In general, some geophysical data can be used directly in geologic interpretations. Other geophysical data require considerable processing before the data can be interpreted (Zohdy et al., 1980).

Available data of (64) wells log descriptions has been used to interpret the VES points; the distributed boreholes covered the study area in the boreholes distribution map. Based on apparent resistivity variations of various formations and sequences, the study area was divided into three sectors; upstream area, middle area and downstream area that shown in Figure (1).

5.2.1 Upstream area

The upstream part of the study area started from Showak town and include; Showak area, Umm Gargoor refugees camp, Upper Atbara and Setit dams areas and terminated at Wad Elhelew town, (Fig. 1). In the Showak area, the resistivity values are ranging between (2 – 600) Ωm. The dominant types of curves are HKH and KH types indicating 7-8 layers shows tow conductive zones, (Table 1). River Atbara sediments are located at shallow sub surface layers, started from 10 m, in which the SWL is ranging between (3-7) m, recorded at the near shallow boreholes. The remaining conductive zone characterized the aquifers that consist of Cretaceous Sandstone. In Umm Gargoor area, the resistivity values are ranging between (6 – 200) Ωm. The dominant curves types are HA, AH indicating 7 layers shows one conductive zone represented by Cretaceous Sandstone. The SWL recorded in some boreholes drilled inside the refugees camp, ranging between (70- 73) m.

In Wad Elhelew area, the resistivity values is ranging between (12– 300) Ωm. The dominant curves types are HKH and KH indicating 6 layers shows one conductive zone composed of Cretaceous Sandstone and intruded by thick layer of basaltic rocks. The SWL observed in some boreholes supplied Wad Elhelew town, ranging between (25- 41) m. Upper Atbara and Setit dams areas are divided into two areas Gedaref area and Kassala area. In Gedaref area the resistivity is generally ranging between (2 – 600) Ωm. The dominant curves types are HA, AH and A. The HA and AH curves indicating 6 -7 layers shows suitable conductive zone, while the (A) curves type in general shows transition of resistivity to high values which they indicate high compacted mudstones over the basement complex.

Generally the sequence in Gedaref area is referring to very hard high deformed sandstone formation. In Kassala area, the resistivity is generally ranging between (10 – 600) Ωm. The dominant curves types are A, HA, HKH and KH curves, (Fig. 3). The KH and HKH curve types indicating 5-7 layers shows conductive zone especially if the apparent resistivity is range between (20-90) Ωm. Generally The VES data in the Dam's area reflect the resistivity layering of the subsurface. The area is known to be a basin in which relatively thick of (Cretaceous sedimentary rocks/Nubian sandstone/Gedaref sandstone) according to the some authors classifications. The SWL in the Dam's area observed in the nearest wells is ranging between (45 – 57) m.

Table 1. The interpreted resistivity curves types of the upstream.

Layer	Depth(m)	Resistivity (Ω.m)	Lithological description
1	0-1	2-60	Superficial deposits
2	1-5	100-450	Dry friable formation
3	5-20	2-32	Clay, sticky and compact
4	20-30	60-120	Cretaceous Sandstone / River Atbara sediments (very near to the River)
5	30-110	100-300	Intruded basaltic rocks (Fractured and saturated in the top and very hard and dry in the below)
6	110- 140	20-80	Aquifer zone (Cretaceous Sandstone, Medium to coarse grained various in colour)
7	140-160	5-90	Mud stone and shale over basement complex
8	>160	>600	Basement complex(granite and quartzite)

5.2.2 Middle area

The middle part of the study area extended from Shagarab villages (East and West) which are located on the both sides of the River Atbara up to north of Showak town and represented a large part of the study area, (Figure 1). In the middle area the resistivity values are generally ranging between (3 – 400) Ωm. The dominant types of curves are KH, KHA and A. The KH and KHA curves indicating (4-5) layers evidence rich water bearing zones, (Table 2 & Figure 4). The area representing a basin in which relatively thick river sediments (River Atbara sediments) of varying grain size occur in considerable thickness below the surface. The (A) curve type indicating high values of resistivity represented the basaltic rocks overlain the basement complex. At a distance from the River Atbara, a dry and compacted intruded layer of basaltic rocks occurred instead of River Atbara sediments. The SWL in the middle area as observed in the wells within the middle area ranging between (9 –10) m near the River Atbara and (20-25) m away from the river.

Table 2. The interpreted resistivity curves types of the middle area.

Layer	Depth (m)	Resistivity (Ω.m)	Geological term
1	0 – 10	10 – 300	Superficial deposits (silts and fine sands).
2	10 – 20	1-20	Confining clayey layer.
3	20 – 60	20-70	River Atbara sediments, partly saturated (gravel and medium to coarse sand).
4	60 – 120	100-300	Intruded basaltic rocks (Fractured and saturated in the top and very hard and dry in the below)
5	> 120	> 500	Basement complex (granite and quartzite)

5.2.3 Downstream area

The downstream part of the study area started from the north of Shagarab villages (East and West) up to Khashm El Girba dam, (Figure 1). In the downstream area the resistivity is generally ranging between (10-500) Ωm. The dominant types of curves is A type indicating (3-4) layers shows low resistivity represent the superficial deposits which dominated by clayey layer overlain the basaltic rocks of higher resistivity values over the basement complex, (Table 3 & Figure 5). This area considered as non-water bearing formation. In some places in downstream area and very near to River Atbara the sequences included thin layer of River Atbara sediments as water bearing formation. The fractures and joints of basaltic rocks which are recognized at the downstream area make it as water bearing unit within the river basin which is not far than 500 m from the river and recharged direct from the River Atbara. The SWL in the downstream area ranging between (6 – 8) m as observed from the existing wells.

Table 3: The interpreted resistivity curves of downstream area.

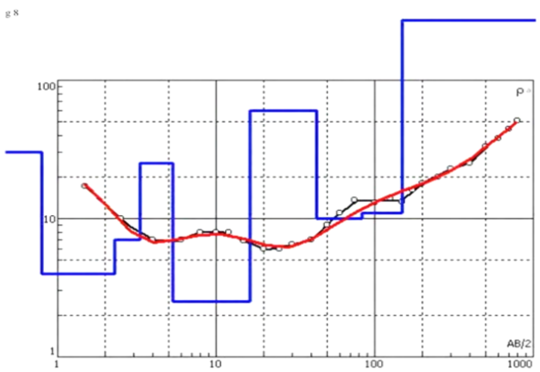
Layer	Depth (m)	Resistivity (Ω.m)	Geological term
1	0 –10	10 –300	Superficial deposits (silts and fine sands).
2	10 - 30	30 – 40	River Atbara sediment, rich water bearing formation (only very near to the River) / Clay, sticky and compact (Away from the River)
3	30 –100	60– 80	Intruded fractured basaltic rocks (saturated in the top and very hard and dry in the below)
4	>100	>100	Basement complex (granite rocks)

6. The geo-electrical sections

The geo-electrical sections in the study area were constructed using the results of the interpretation of (VES) curves and the existed boreholes data. There are three geo-electrical sections constructed in the study area in E-W direction. The geo-electrical sections No. 1, 2 and 3 are located in the upstream area, middle area and downstream area respectively, (Fig. 9).

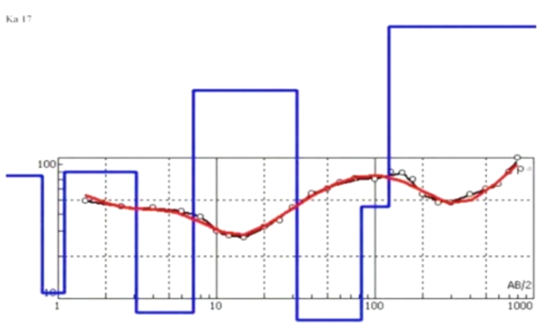
6.1 Geo-electrical section No. 1

This section includes VES158, VES160, VES166, VES162, VES163,8 VES2, VES 91 and VES88. This section started from the eastern bank of the River Setit (Kassala area) and terminated at the western bank of the River Atbara (Gedaref area) that extended in E–W direction. This section consists of 7 layers. The top layer composed of superficial deposits with thickness ranging between (5-20) m of resistivity values ranging between (2-30) Ω.m. A thin layer composed of dry sand underlies the top layer with thickness ranging between (6 -14) m of resistivity values ranges from 100 to 450 Ω.m. This layer occurred on the eastern bank of the River Atbara (Kassala area), thin layer of sandstone sometimes occurred at the surfaces on the western Bank of the River Atbara (Gedaref area) with thickness ranging between (10-25) m of resistivity values ranging between (60-120) Ω.m.



RMS=7.07%

N	1	2	3	4	5	6	7	8	9
ρ	30	4	7	25	2.5	60	10	11	2686
h	0.8	1.5	1	2	11	27	40	65	
d	0.8	2.3	3.3	5.3	16.3	43.3	83.3	148	
Alt	-0.8	-2.3	-3.3	-5.3	-16.3	-43.3	-83.3	-148.3	

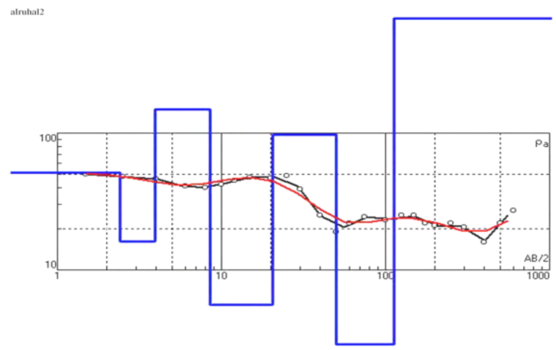


RMS=5.7%

N	1	2	3	4	5	6	7	8
ρ	75	11	80	8	300	7	45	4411
h	0.8	0.3	2	4	25	50	40	
d	0.8	1.1	3.1	7.1	32.1	82.1	122	
Alt	-0.8	-1.1	-3.1	-7.1	-32.1	-82.1	-122.1	

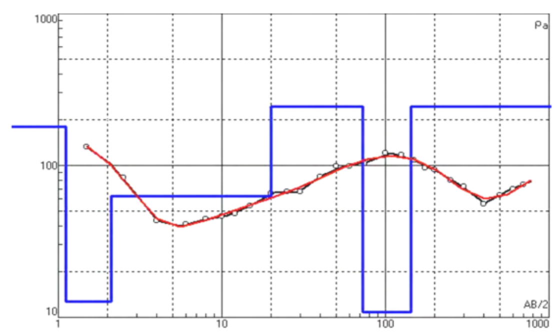
Fig. 3. Typical measured resistivity curve in the upstream area.

A confining layer of clay underlies the dry sandy layer with thickness ranging between (10 - 50) m of resistivity values ranges from 2 to 30 Ω.m. The intruded basaltic rocks underlies the clayey layer with thickness ranging between (20 -90) m of resistivity values ranges from 100 to 300 Ω.m that concentrated on the eastern bank of the River Atbara (Kassala area) and disappeared at the Gedaref area, which attached to western bank the River Atbara. The low resistivity of the basaltic rocks indicated saturated zone while the high values indicated unsaturated zone.



Error = 7.38%

N	1	2	3	4	5	6	7
ρ	51.6	16.3	149	5.59	97.3	2.84	1017
h	2.4	1.53	4.55	12.2	29.1	62.9	
d	2.4	3.93	8.48	20.6	49.7	113	
Alt	-2.398	-3.927	-8.48	-20.64	-49.75	-112.6	



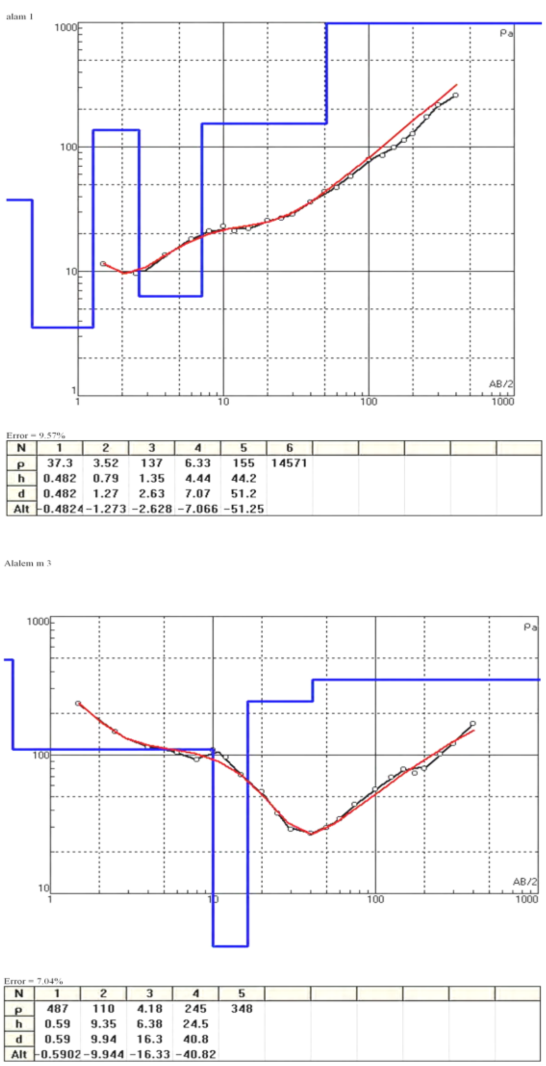
Error = 3.57%

N	1	2	3	4	5	6
ρ	180	12.7	63.1	242	10.9	244
h	1.12	1	18	52.4	70.7	
d	1.12	2.12	20.1	72.5	143	
Alt	-1.116	-2.119	-20.09	-72.52	-143.3	

Fig. 4. Typical measured resistivity curve in the middle area.

The basaltic rocks overlain the aquifer zone which is composed of sandstone with thickness ranging between (20-65) m of resistivity values ranges from 10 to 70 Ω.m, the low values indicated fine grained sandstone while the high values indicate the coarse grained sandstone. Generally this layer of sandstone is representing rich water bearing formation. The mudstone layer started from W of VES 163 and terminated at the end of the section in the Gedaref area at the west bank of the River Atbara with thickness ranging between (30 - 40) m of resistivity values ranges from 1 to 5 Ω.m.

The lowest layer in this section is the basement complex at depth ranging between (120-160) m of resistivity values ranges from 600 to 2100 Ω.m, (Figure 6). All point in this section shows promising sites for drilling deep boreholes except VES 158 which is not recommended for drilling due to the existence of thick basaltic rocks and disappearing of the sandstone layer. Two VES points (VES 91 and VES 88) confirmed by drilling and productive good yield. This cross section confirmed that the western bank of the River Setit was uplifted. The data from Dams Implementation Unit displayed River Setit is highest by 4 meters than River Atbara.



N	1	2	3	4	5	6
ρ	37.3	3.52	137	6.33	155	14571
h	0.482	0.79	1.35	4.44	44.2	
d	0.482	1.27	2.63	7.07	51.2	
Alt	-0.4824	-1.273	-2.628	-7.066	-51.25	

N	1	2	3	4	5
ρ	487	110	4.18	245	348
h	0.59	9.35	6.38	24.5	
d	0.59	9.94	16.3	40.8	
Alt	-0.5902	-9.944	-16.33	-40.82	

Fig. 5. Typical measured resistivity curve in the downstream area.

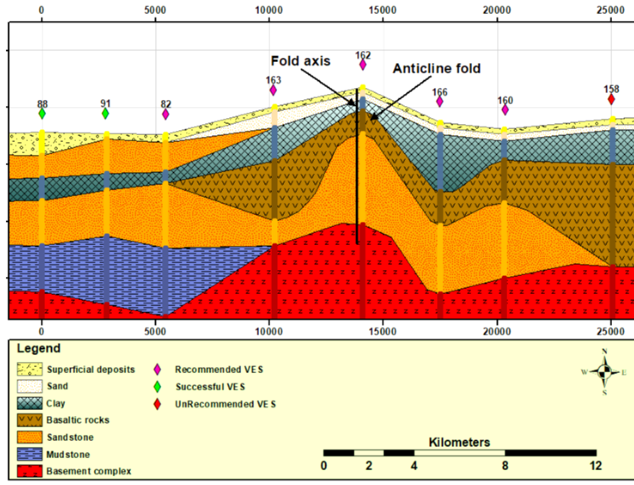


Fig. 6. Cross section No. 1.

6.2 Geo-electrical section No. 2

This section contain VES119, VES136, VES42, VES40, VES43 and VES45 that started from the eastern side of the River Atbara within the middle stream part of the study area and extended in E - W direction. This section constructed from 6 layers. The top layer consist of superficial deposits with thickness ranges from 10 to 30 m and of high resistivity values ranging between (10-300) Ω.m, indicating the existence of dry sand. This superficial layer terminated at VES40. The top layer underlies by clayey layer with thickness ranges from 13 to 40 m of resistivity values ranging between (3-60) Ω.m.

A thin dry sandy layer occurred on the western and eastern sides on the cross section and disappeared somewhere in the middle. The sandy layer underlies by partly saturated layer composed of River Atbara sediments with thickness reaches 40m and resistivity values ranges from 20 to 70 Ω.m. A thick layer of intruded basaltic rocks underlies the River Atbara sediments and overlain the basement complex with thickness ranging between (60-110) m of resistivity values ranges from 100 to 300 Ω.m.

The depth to basement complex ranging between (113-160) m of the resistivity values ranging from (300-500) Ω.m, (Figure 7).The aquifer zone in this section characterized by the River Atbara sediments at stations (VES136, VES42) and saturated fracture zone of the basaltic rocks at station (VES119). Generally this section affected by geological structures, VES119 and VES136 are confirmed by drilling with good yield while VES42 represents the promised site for drilling borehole, VES40,VES43 and VES45 are not recommended that they located out of the aquifer zone.

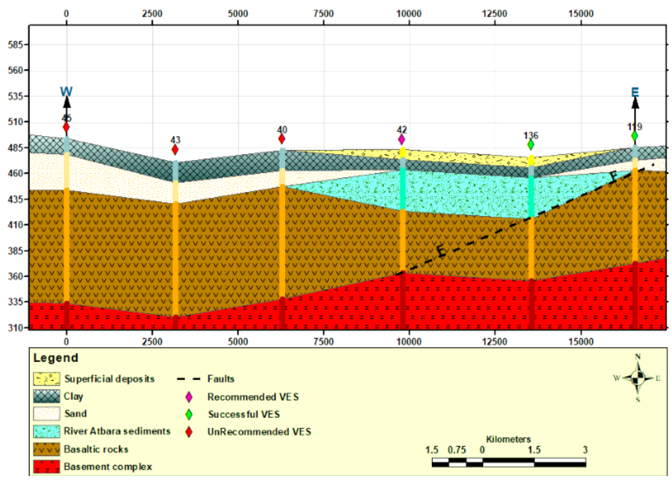


Fig. 7. Cross section No. 2.

6.3 Geo - electrical section No. 3

This section includes VES116, VES110, VES112, VES29 and VES8, situated on the downstream part of the study area and extended in E–W direction. The sequences in this section are 5 layers; superficial layer as in VES112 and VES29, which are located near the river. The resistivity values of superficial layer ranges from 10 to 300 Ω.m with thickness reaches 10 m. The low resistivity values in the superficial layer represent clay layers, while the high values of resistivity indicate dry sandy layers. A clayey layer located away from the river and detected by VES116, VES110 and VES8 with resistivity values ranges from 10 to 75 Ω.m with thickness reaches 10 m. These top layers (Superficial deposits and clay) underlies by aquifer formation composed of River Atbara sediments occurred very near to the river and defined by VES112 and VES29 in the middle part of the cross section.

The resistivity values of the River Atbara sediments ranges from 30 to 40 Ω.m with thickness ranging between (10-15) m. A layer of intruded basaltic rocks overlain the basement complex with resistivity values ranges from 60 to 300 Ω.m with thickness ranging between (20 -50) m. These basaltic rocks are fractured and saturated at the top part (near the recharge source) and very hard and dry below. The bottom layer of the section represented by the basement complex with resistivity values rang between (100 - 500) Ω.m. The depth to the basement reaches 40 m near the river and 70 m at the plain area, (Figure 8). All VES points are recommended for drilling of shallow boreholes except VES 116 which is situated out of the aquifer zone.

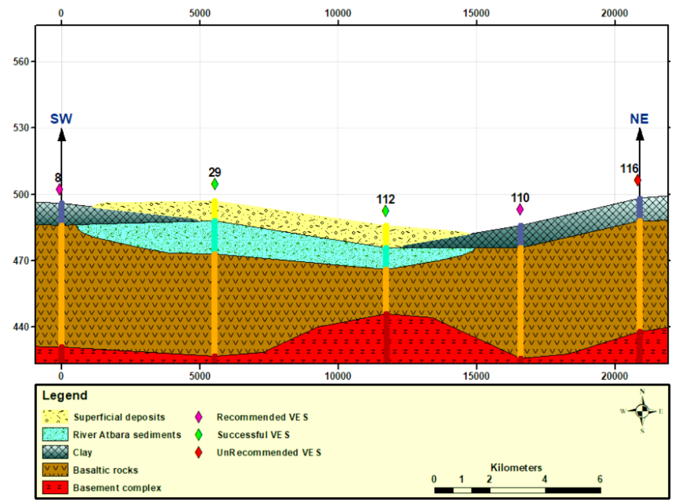


Fig. 8. Cross section No. 3.

7. Geophysical findings

The finding of Water potentiality map, (Figure 9), constructed from the result of the (177) vertical electrical sounding, which were conducted in the study area can be summarized in; (88) points are promising for drilling boreholes (28 points of them were confirmed by drilling), while (80) points are not promising after data interpretation and (9) points were conducted at productive boreholes for calibration.

The Aquifer in the study area seems to be wider upstream and gets narrower downstream. The promising and productive zones were consist of:

- River Atbara sediments extended along the River Atbara from the upstream area to downstream area, except on the eastern part of the downstream area near Khashm el Girba dam.
- Cretaceous sandstone which is occurred in the upstream part of the study area including (Wad Elhelew area, Upper Atbara / Setit dams area , Showak area and Um Gargoor area).
- Saturated fractured basaltic rocks which covered the area attached to the River Atbara banks and recharged directly from the River.

8. Conclusions

The geophysical investigations confirmed that the depth to the basements rocks, which formed the bottom layer of the groundwater varies between (120-250) m in the upstream area, (120-150) m in the middle area and (15-75) m in the downstream area. The aquifer system in the study area consisted of Cretaceous sandstone in the upstream area, River Atbara sediments extended from the midstream area to downstream and saturated basaltic rocks in the downstream area. The thickness of the aquifer varies between varies between (25-50) m in the upstream area, (15-25) m in the middle area and (13-15) m in the downstream area.

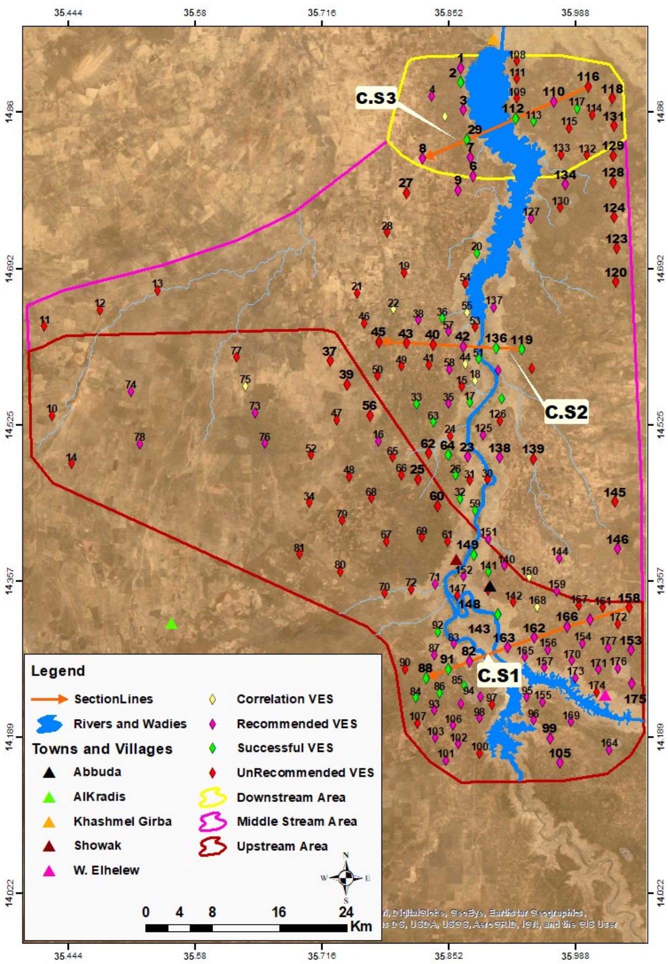


Fig. 9. Water potentiality map (Confirm by drilling data).

The vertical electrical sounding (VES) technique indicates that the aquifer thickness of River Atbara sediments is controlled by the undulations of the basement complex configuration and by the lateral and vertical facies changes in the area. The aquifer thickness of Cretaceous sandstone zone is controlled by the thickness of the intruded basaltic rocks and undulations of the basement complex. The saturation of the basaltic rocks is effected by the distance from the river which it has being more saturated near the River Atbara.

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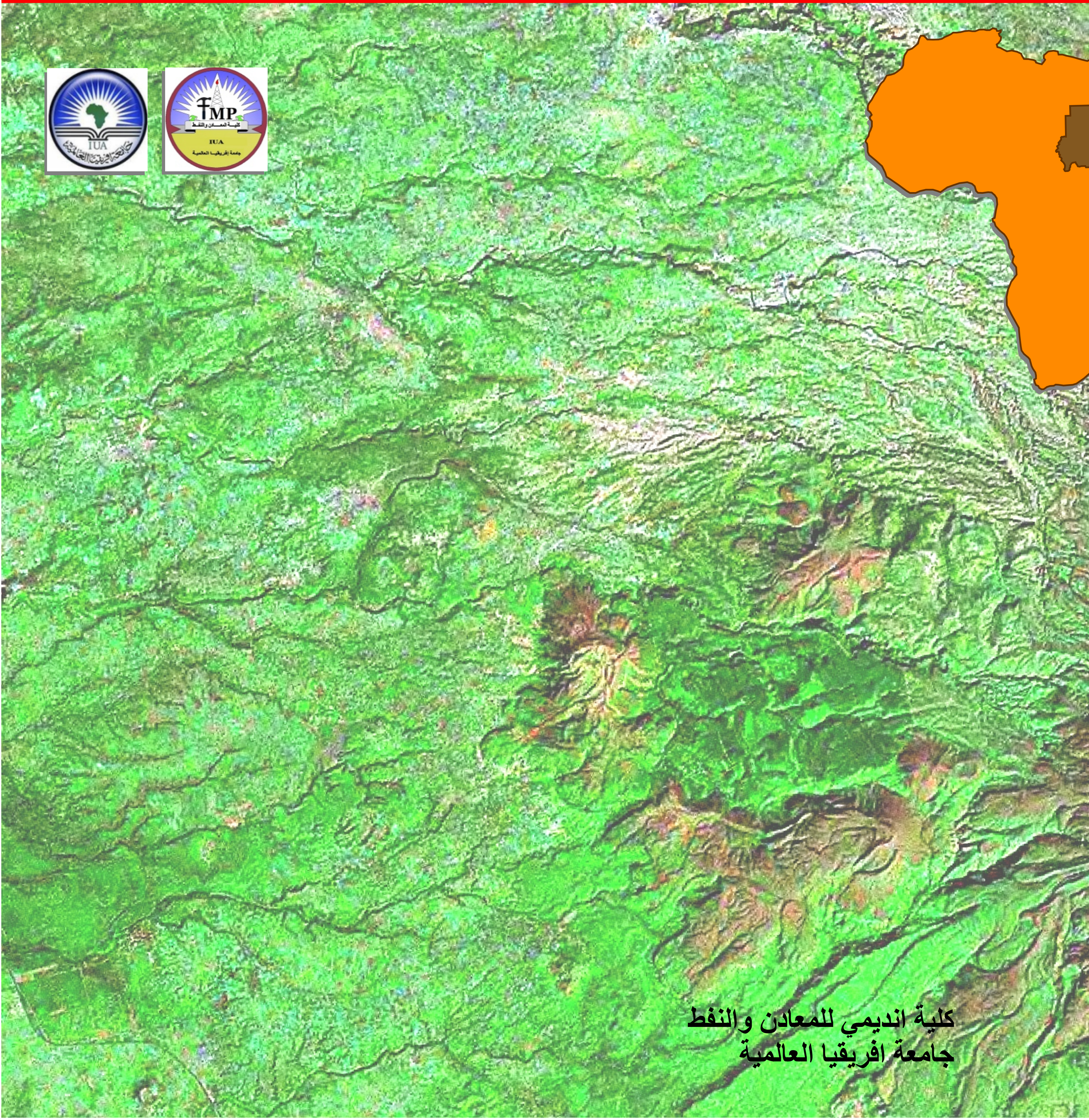

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